Living With A Star

Gauging the space weather

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The LWS Philosophy

- At the center of our solar system lives a highly variable magnetic star.

- A lot can happen in 93 million miles to change the space weather at Earth

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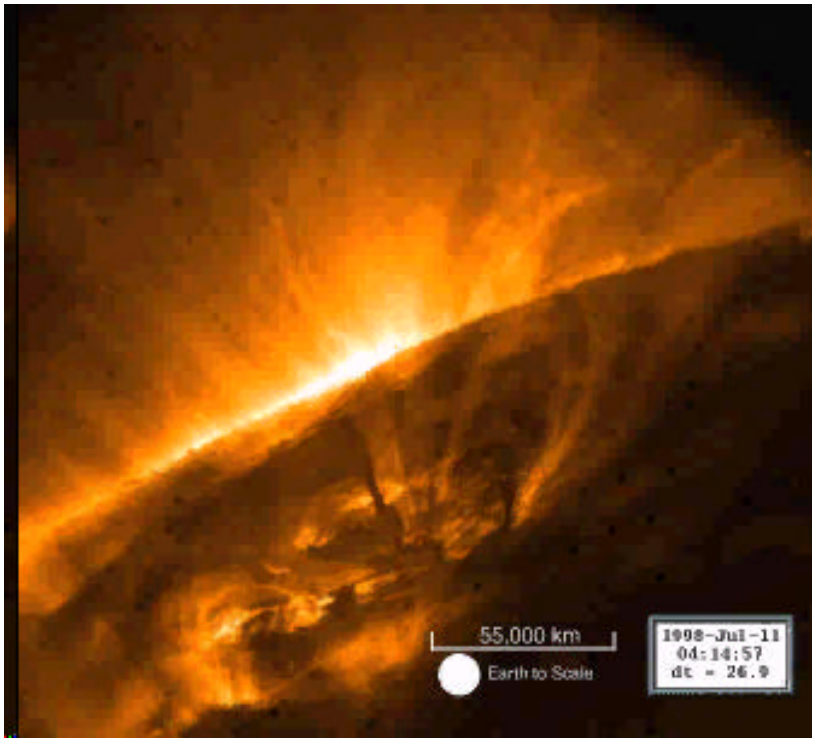
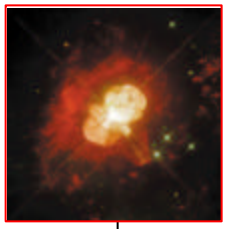
LWS Mantra

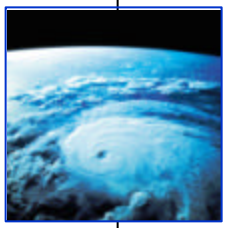
Develop the scientific understanding necessary to effectively address those aspects of the connected Sun-Earth system that directly affect life and society.

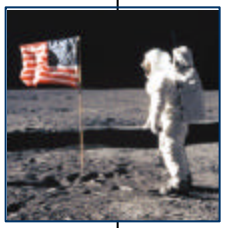


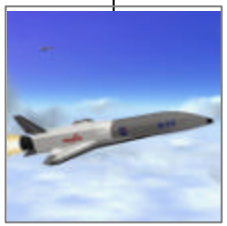
AGENCY LEVEL GOALS & OBJECTIVES

The LWS program is a cross-cutting initiative whose goals and objectives have the following links to each of the four NASA Strategic Enterprises:









- ***Space Science*: LWS quantifies the physics, dynamics, and behavior of the Sun-Earth system over the 11-year solar cycle.**
- ***Earth Science:* LWS improves understanding of the effects of solar variability and disturbances on terrestrial climate change.**
- ***Human Exploration and Development:* LWS provides data and scientific understanding required for advanced warning of energetic particle events that affect the safety of humans.**
- ***Aeronautics and Space Transportation:* LWS provides detailed characterization of radiation environments useful in the design of more reliable electronic components for air and space transportation systems.**

SOCIETAL CONSEQUENCES OF SOLAR VARIABILITY

Human Radiation Exposure

- Space Station
- Space Exploration and Utilization
- High Altitude Flight

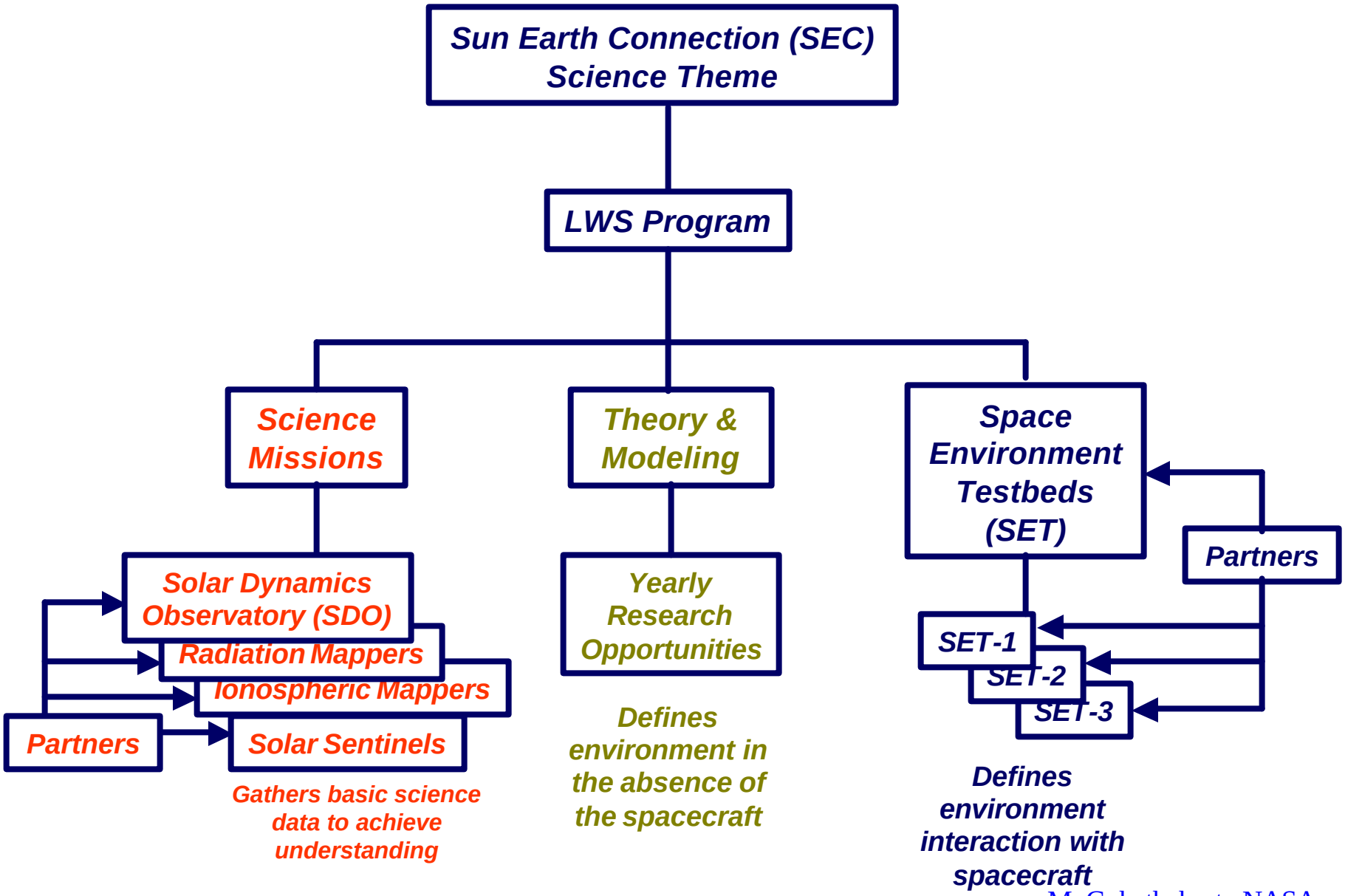
- **Impacts on Technology**
  - Space Systems
  - Communications, Navigation
  - Terrestrial Systems

- **Terrestrial Climate**
  - Short Term
  - Long Term

LWS OBJECTIVES

- **How and why does the Sun vary?**
- **How does the Earth respond?**
- **What are the impacts on life and society?**
  - **Understand solar variability and its effects on space and Earth environments.**
  - **Obtain information for mitigating undesirable effects of solar variability on human technology.**
  - **Understand how solar variability can affect life on Earth.**
    - **To enable better understanding of global climate change caused by both natural (solar variability, volcano eruptions) and human drivers.**
    - **To better predict how stellar variability affects life in other stellar systems.**

Living With a Star (LWS) Program Architecture



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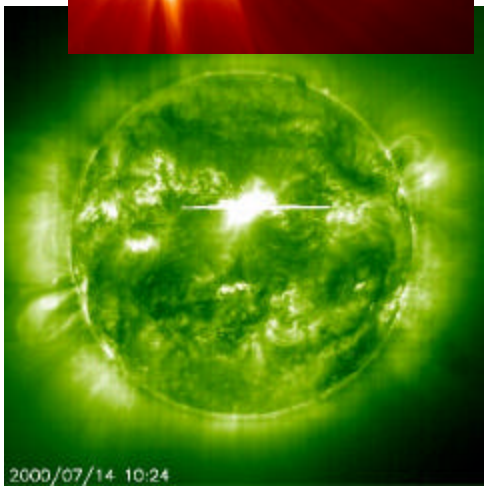
SDO Top Level Goals

- To understand basic physical processes in the Sun and its extended outer atmosphere
- To be a part of the Living with a Star (LWS) program which aims to understand the coupled physics of the Sun, the interplanetary medium, the Earth's magnetosphere and atmosphere, and Global Change
- To develop predictors of various solar processes to aid in the forecasting of events of potential danger or damage to workers in space, scientific and commercial spacecraft, high-altitude aircraft, and the Earth'scommunications and power distribution systems.



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SDO Scientific Goals

- To understand how magnetic fields appear, distribute, and disappear from their origin in the solar interior to 18 solar radii from the solar surface.

- To understand the magnetic topologies that give rise to rapid high energy release processes that occur on scales from a thousand to many hundreds of thousand kilometers.

- To study and gauge the dynamic processes which influence space weather phenomena

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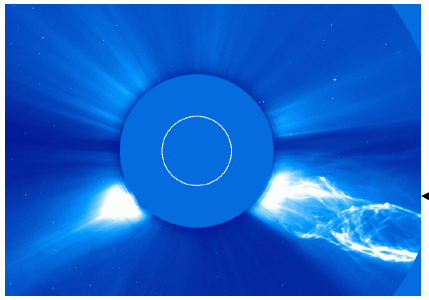
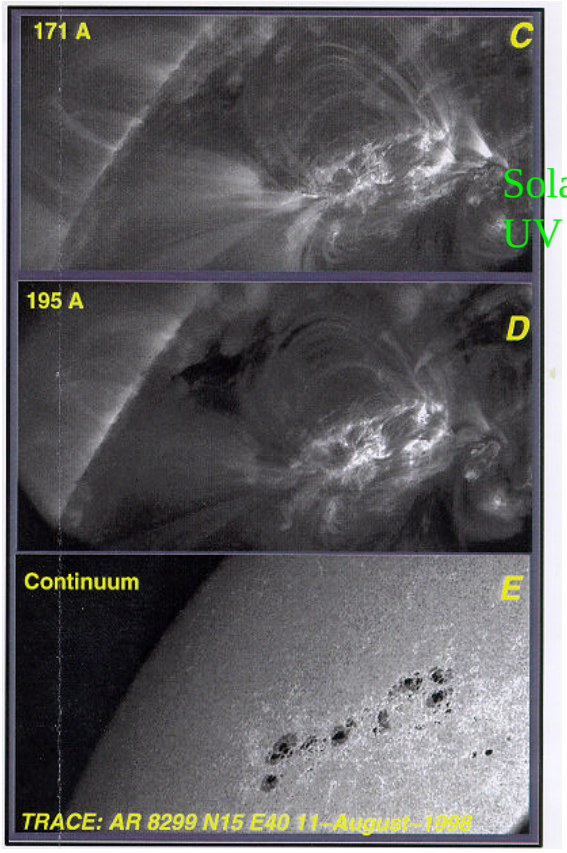
Solar Dynamics Observatory - Next Generation SOHO



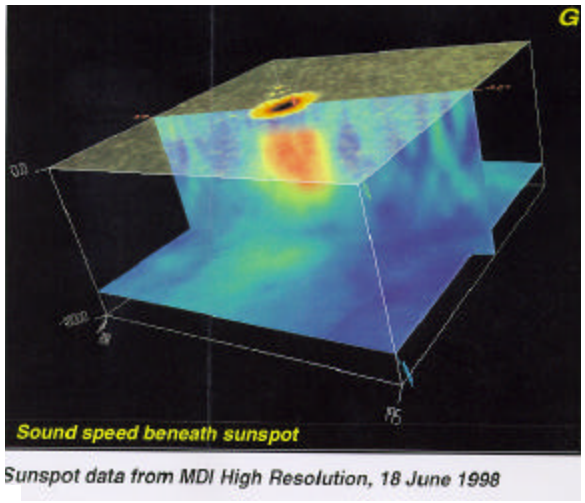
Imaging CME'S

- **Investigating solar dynamical processes and phenomena**
- **Observing development of magnetic and subsurface phenomena related to 1) flare &CME energy storage & triggering 2) The solar dynamo driving the solar cycle.**
- **High data rate from GEO orbit for studying dynamics (SOHO limited by low data rate from L1)**



Solar EUV and UV Irradiance

Imaging Magnetic Structures (rapid time sequences – "movies")

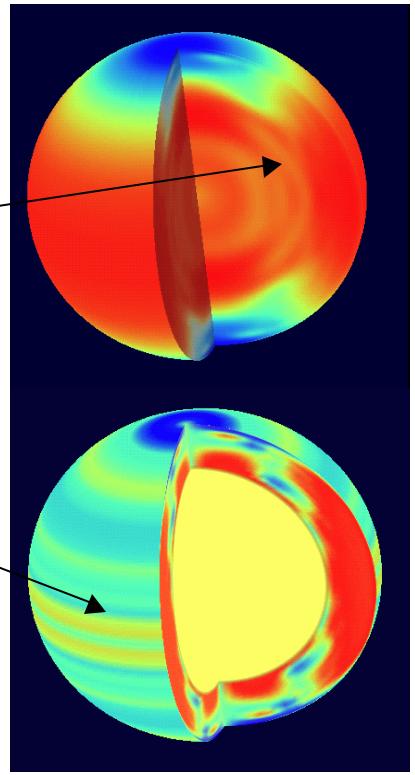


Imaging Subsurface Structures

Red: Faster Rotation
Blue: Slower Rotation

Solar Dynamo?

Link to solar cycle?



Imaging Solar Interior

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The Solar Dynamics Observatory (SDO)

- ***Status***
  - **Geosynchronous orbit**
  - **3-axis stabilized spacecraft**
  - **5-year primary lifetime**

  Space craft to be built by Goddard Space Flight Center

  – **Instrument Payload selected in August, 2002**
    - **Three investigations selected with 4 highest priority instruments (HMI, AIA, SIE & WCI) and one high priority instrument (HVMI)**

- ***Launch – August 2007***

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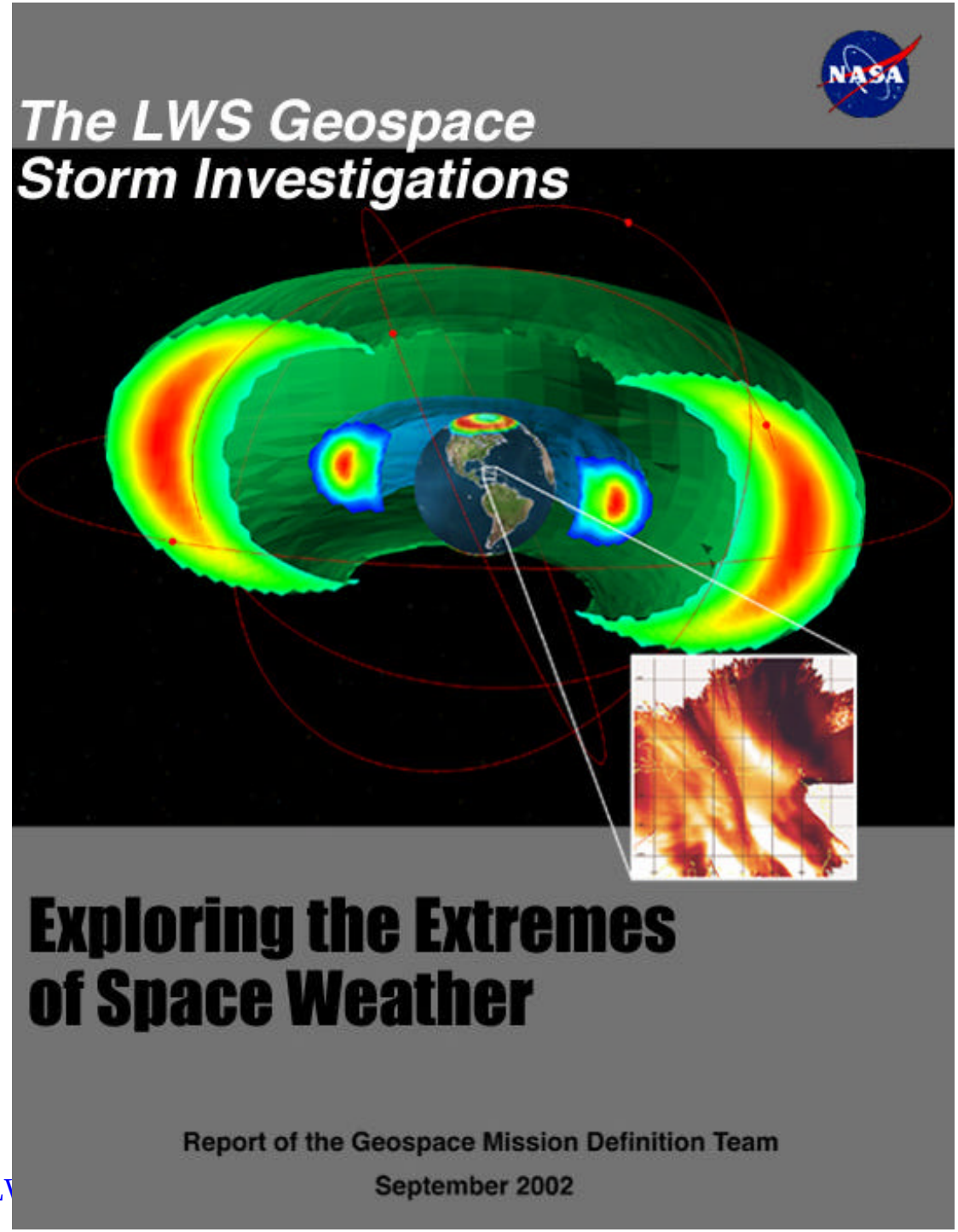

The LWS Geospace Program

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Objective and Goal

•The overarching objective of the Geospace program for LWS is to develop a scientific understanding of the effects of solar variability on those geospace phenomena that most directly affect life and society.

•Science of phenomena that most directly affects life and society has the highest priority

•Preliminary analysis indicates that these occur in the radiation belts, the thermosphere/ionosphere and the polar cap.

Understanding *and* characterization is important for developing the needed physics-based and empirical space environment models and for diagnosing and predicting the wide variety of space weather effects:

- global climate change
- satellite anomalies
- satellite drag
- communication/navigation/radar disruptions
- human exposure to radiation

•**Goal is to discover enabling science**

-Characterization vs. understanding

-Operations is not in charter

Priority Science Focus

- Outer-zone relativistic electrons
  - Production of radiation enhancement events
  - Acceleration, transport, local vs. extended, shock vs. diffusion
  - Relativistic electron loss mechanisms
- Mid-latitude ionospheric storms and irregularities
  - Solar EUV forcing of ionosphere
  - Positive-phase ionospheric storms
  - Negative-phase ionospheric storms
  - Irregularities, scintillations (in-orbit)
- Ring current for context
  - Currents produce **B** that moves radiation belts
  - Potential source of free energy for waves that produce outer-zone electrons
  - Couples inner-magnetosphere to ionosphere

Societal Consequences

- Outer-zone relativistic electrons
  - Surface and differential charging, deep dielectric charging
  - Single event upsets
  - Astronaut safety
- Mid-latitude ionospheric storms and irregularities
  - GPS accuracy
  - UHF and L-band (GPS) signal reliability (scintillations)
  - Affect HF communications, and OTH radar
  - In-orbit scintillations
- Ring current for context
  - Required for models of inner magnetosphere
  - Required to understand ionosphere-magnetosphere coupling at mid-latitudes or equatorial latitudes
  - Produces currents that have high-latitude consequences, power, oil lines etc.

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Geospace Investigation Vocabulary

- There are two investigations, Radiation Belt and Ionosphere-Thermosphere
- Each investigation is subdivided into
  - Baseline that yields robust understanding of the priority objectives
  - Core (a subset of baseline) that yields substantial progress and reflects budget realities
  - Network-level that yields system wide understanding

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I-T Investigation (Baseline)

- I-T Storm Probes of two identical spacecraft with
  - Plasma density, drift, and density fluctuations
  - Thermospheric wind, density and composition
  - Ionospheric (Ne) altitude profiles
  - In-orbit scintillations
  - Auroral electron precipitation
  - Currents (**B**)
  - AC electric fields
  - 60^0 inc, <500 km altitude, 10^0-20^0 ascending node separation
- I-T mid-latitude imager at GEO, probably FUV for O/N_2 and Ne^2
- EUV spectral flux on Solar Dynamics Observatory- on SDO balance sheet

I-T Investigation (Core)

- Core is one set of measurements that produces substantial progress, used for pricing (feasibility) study, and reflects budget realities
- For each spacecraft remove from baseline
  - Auroral electron precipitation
  - Currents (**B**)
  - AC electric fields

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Radiation Belt Investigation (Baseline)

- Radiation Belt Storm Probes (two identical)
  - 20keV-20MeV electrons
  - B and ULF waves
  - DC E-field
  - B and E VLF waves
  - Ring current ions (20-600keV) and composition
  - Energetic ions (1-200 MeV)
  - Both in sub-GTO and slowly separating
- ENA ring current imager- separate spacecraft
- Plus in LEO, high inc.
  - precipitating energetic electrons
  - proton monitor

Radiation Belt Investigation (Core)

- Remove
  - ENA ring current imager- separate spacecraft
  - LEO, high inc., electron and proton measurements
- Downgrade one spacecraft to Little Brother level with
  - 20keV-1MeV electrons
  - B and ULF waves
  - Ring current ions (20-600keV) and composition

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Network Level Measurements

- Auroral Imager
- Inner Radiation Belt and Slot Investigation
- Electron measurements at GEO to obtain source population
- Increased coverage of solar cycle (more or more rad hard RBSP)
- Increased local time coverage (more RBSP at different local times)

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Reality of the Geospace Program

- We can not afford all elements so…
- Success requires
  - Provision of an L1 solar wind monitor
  - Utilizing known complementary programs
    - High latitude- DMSP, POES, NPOESS
    - Low latitude- C/NOFS
    - GEO- GOES, LANL
    - Plus ground based contributions-radar, ionosondes, micropulsations etc.
  - **International Collaboration**

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Examples of Geospace Science with Societal Consequences

- Mid-latitude ionospheric storms
- Radiation belt variability
- Consequences for theory and modeling

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The Geospace Missions Network

- **Status**
  - **Network science and mission architecture study by Geospace Mission Definition Team (GMDT) is released.**

Concept: Two types of spacecraft:

- **Ionospheric Mappers: 2 spacecraft, 3 year life**
- **Radiation Belt Mappesr: 2 spacecraft, 2 year life**

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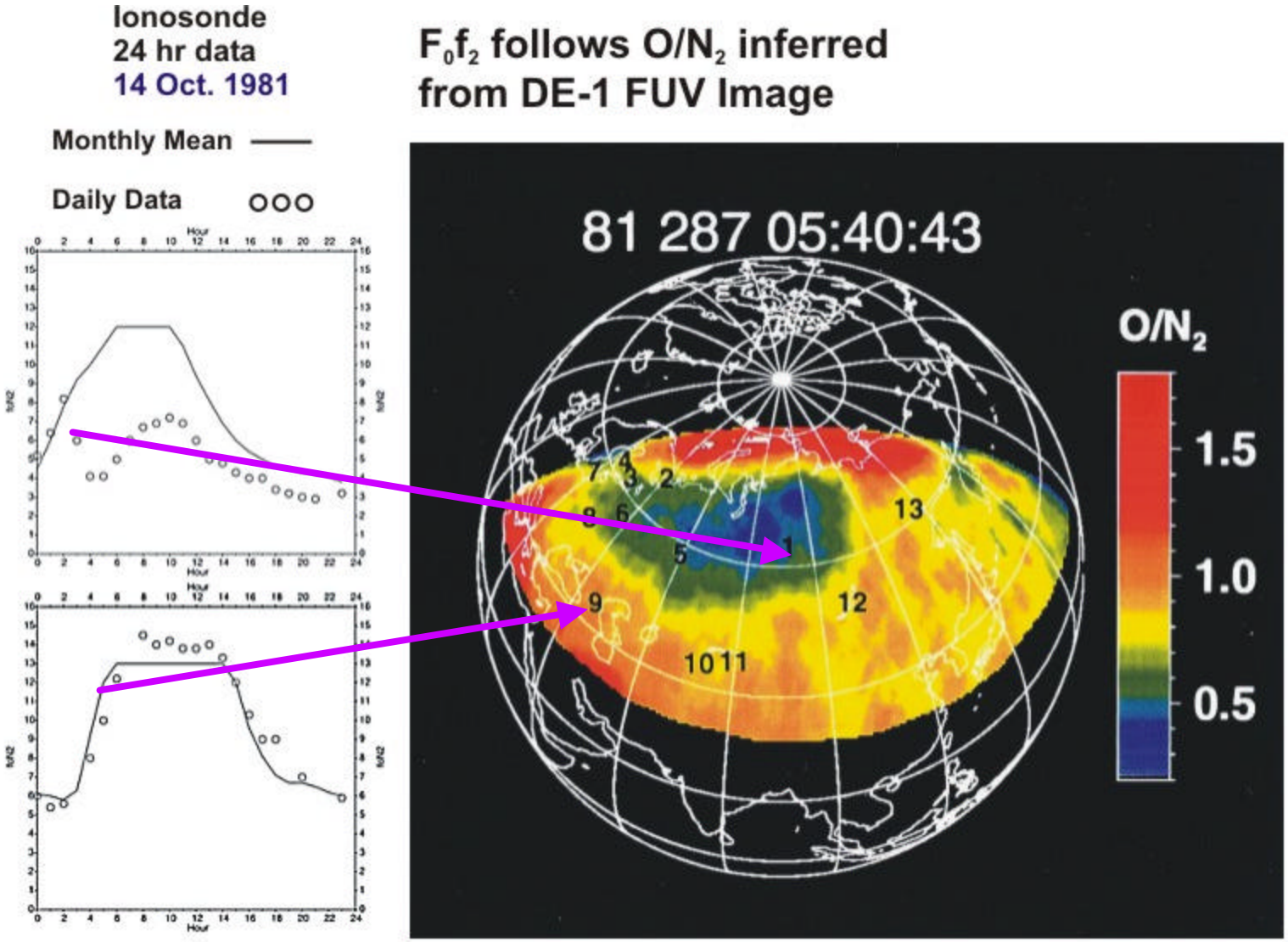
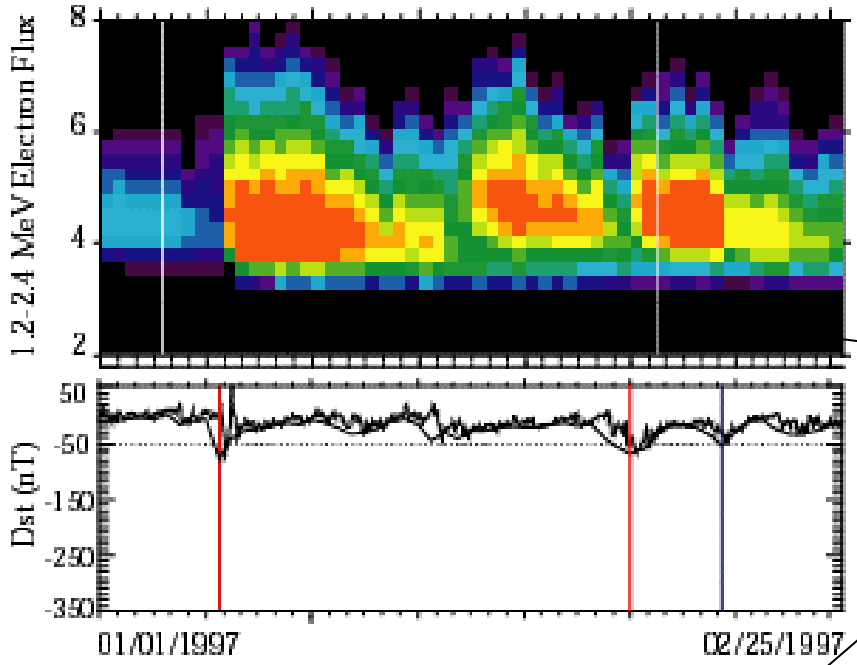
Negative Ionospheric Storm Tracks Region of Low O/N_2



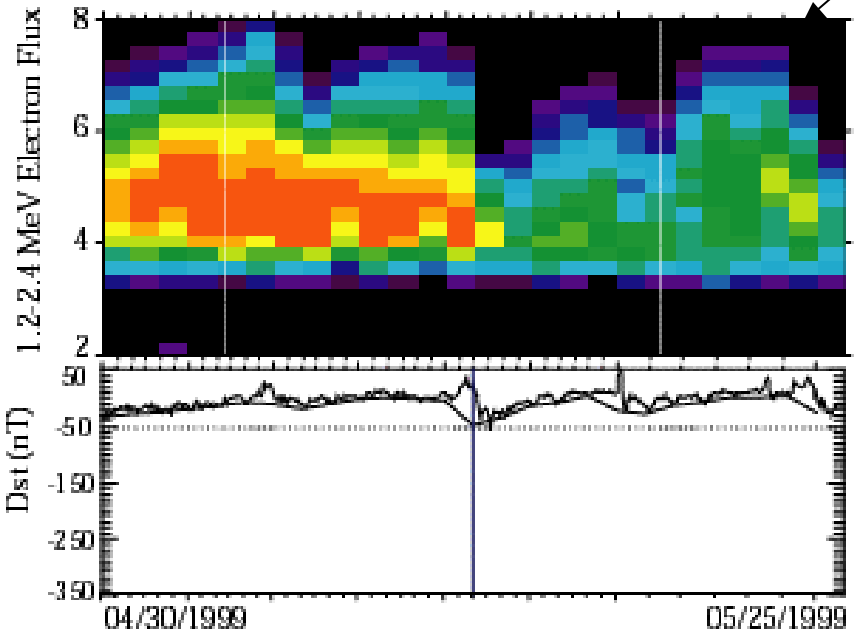
Not All Storms Produce Radiation Belts

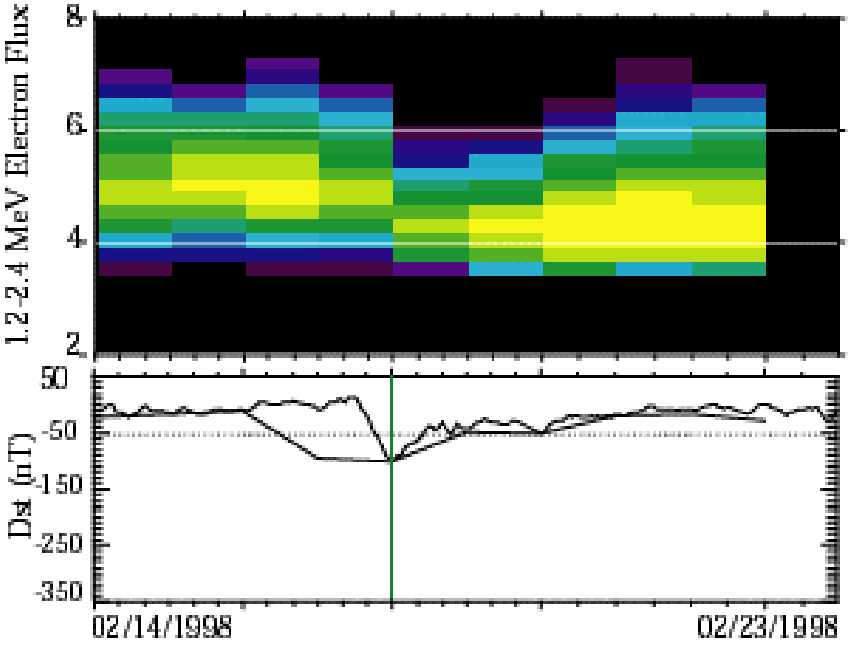


MORE

SAME

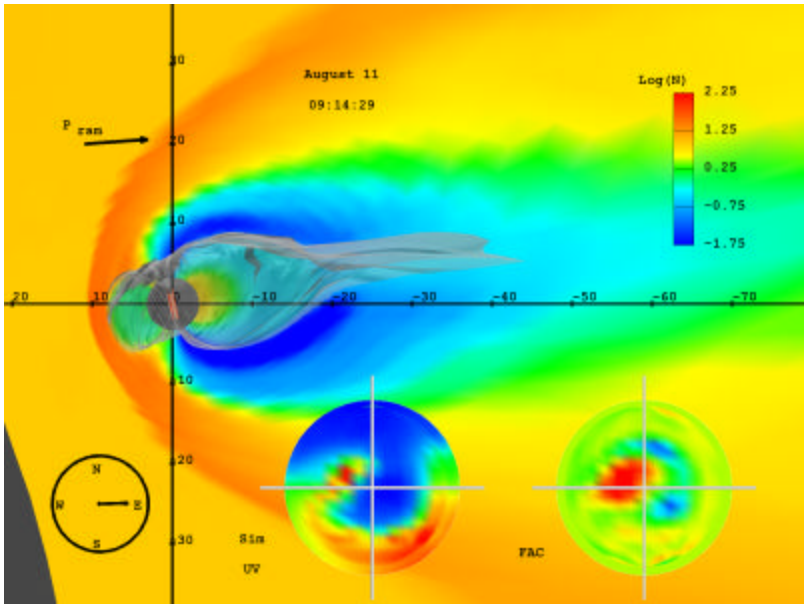
LESS





Societal Benefit Through Enabling Science and Models

- Detailed models of radiation belts for the cost-effective design of spacecraft subsystems, anomaly resolution, and astronaut safety
- Dynamic global ionospheric models applicable to communications, navigation and radar
- Dynamic neutral density models from which to accurately predict satellite drag



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The Solar Sentinel Missions

Goal

Understand the transition and evolution of eruptions and flares from the Sun to the Earth's magnetosphere

Focus areas

- **Determine the structure and long-term climatic variations of the ambient solar wind in the inner heliosphere**
- **Determine how geo-effective solar wind structures propagate and evolve in the inner heliosphere**
- **Determine what solar dynamic processes are responsible for the release of geo-effective events**
- **Determine how and where energetic particles are released and accelerated**

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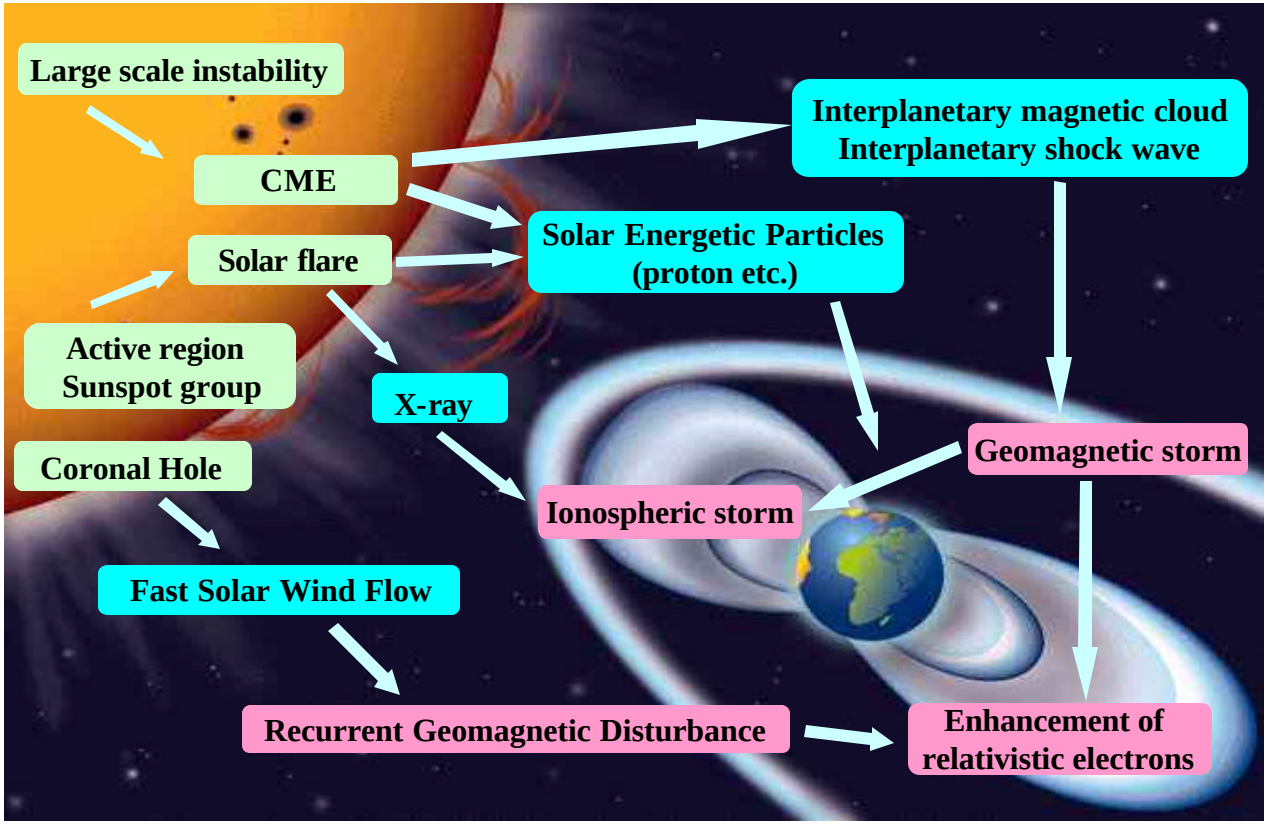
Primary Objectives



Discover, understand and model the connection between solar phenomena and geospace disturbances.

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SOLAR SENTINELS - STATUS

- **Current Mission Concept:**

  - **Four inner heliospheric sentinels at various distances from Sun to study propagation of particles and solar wind structures (e.g. CME's) through inner heliosphere**

  - **Farside Sentinel to observe far side of Sun**

- **Mission Architecture TBD in conjunction with ILWS:**

  - **ESA Solar Orbiter mission addresses several Solar Sentinel objectives**
  - **CRL (Japan) considering an L5 mission**
  - **Brazil is interested in provision of small solar sentinel spacecraft**
  - **Investigation of synergism/potential of including a Solar Probe mission as an ILWS package involving Solar Orbiter, Bepi Colombo, and Solar Probe (common technical issues, complementary data from Solar Probe and Solar Orbiter)**

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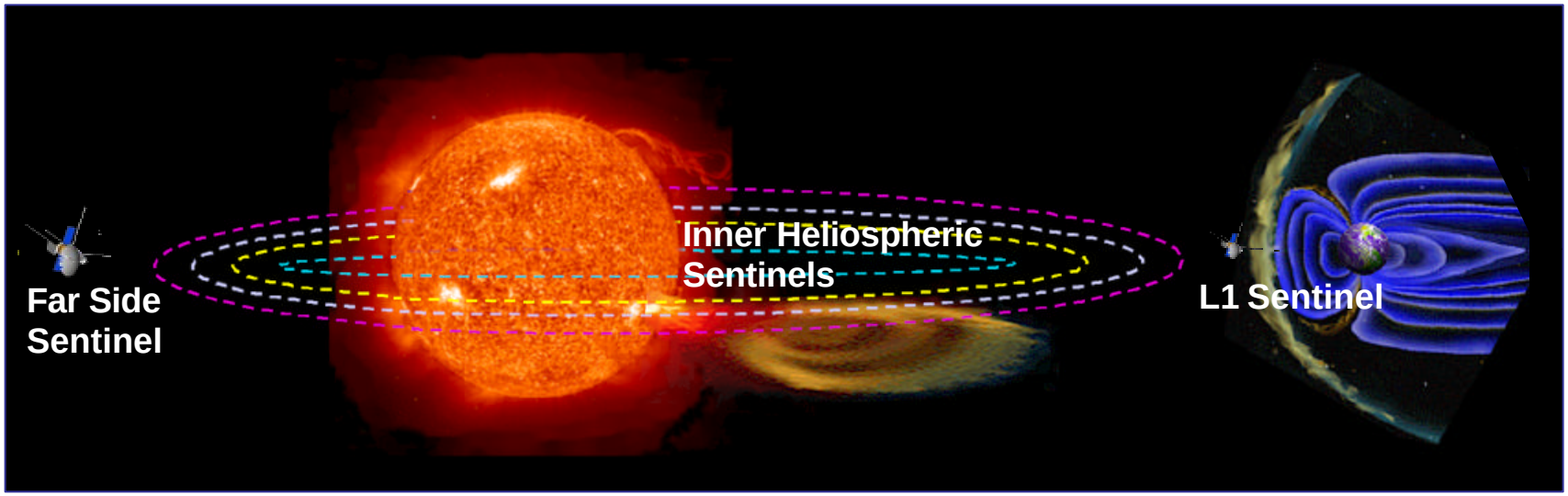
Inner Heliosphere Sentinels ScienceObjectives



- **Determine the structure and long-term (solar cycle and much longer) climatic variations of the ambient solar wind in the inner heliosphere *(in situ)***
- **Determine how large-scale solar wind structures propagate and evolve in the inner heliosphere *(in situ combined with remote sensing)***
- **Determine what dynamic processes are responsible for the release of geoeffective events *(in situ combined with remote sensing)***
- **Determine how and where energetic particles are released and accelerated *(in situ combined with remote sensing)***

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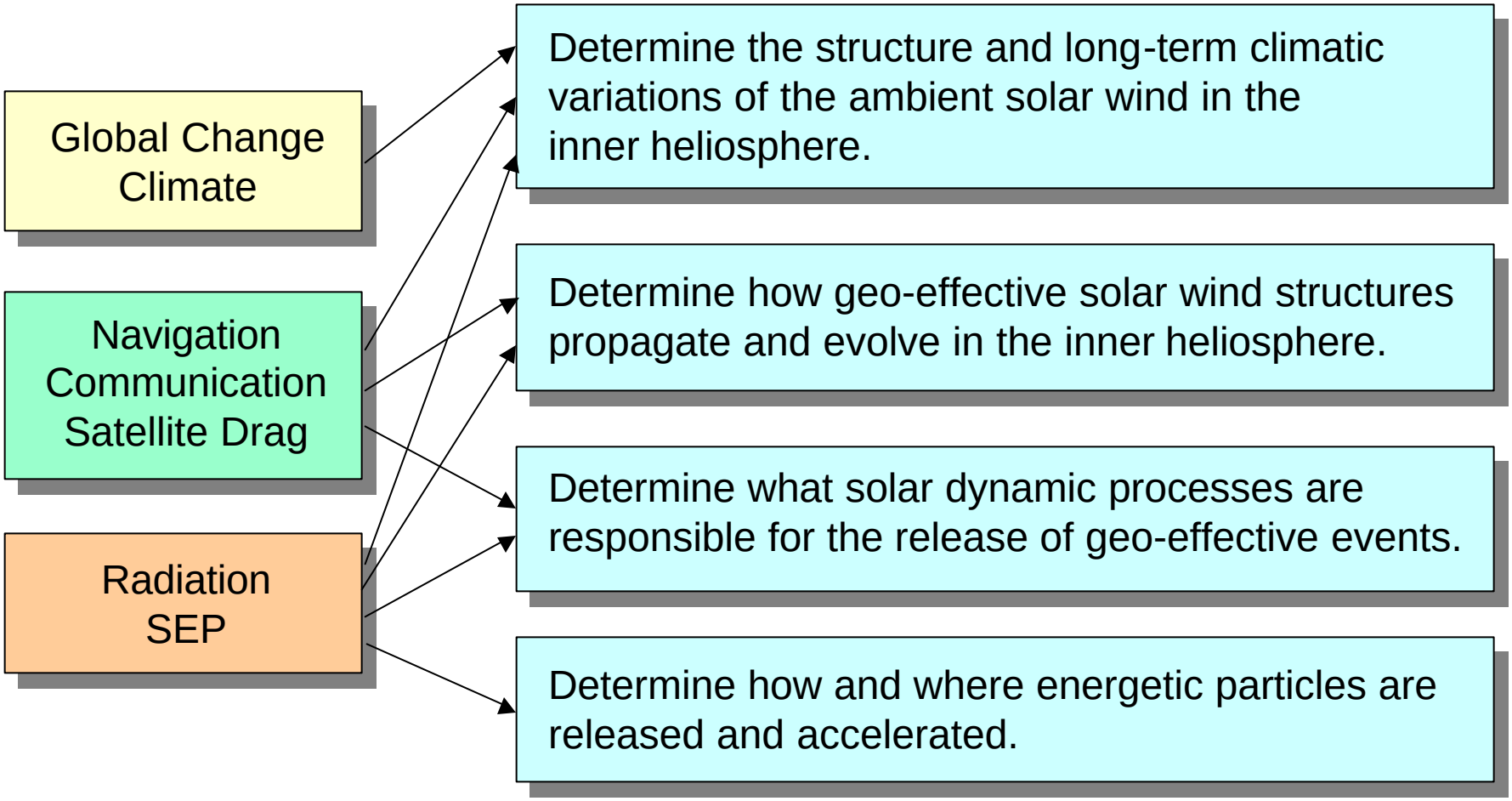
Societal Impacts

Science Objectives



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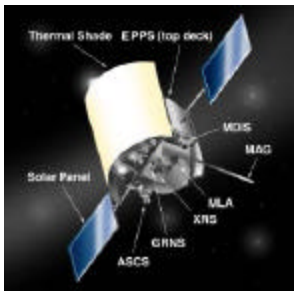
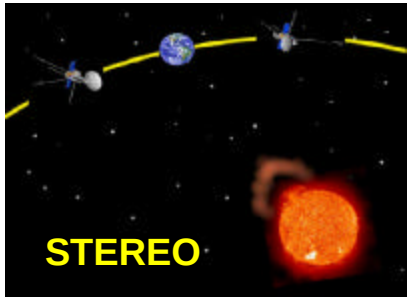
Additional Opportunities

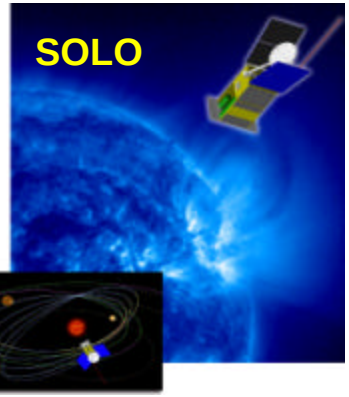
When possible, fill observational gaps using future NASA missions:
STEREO, MESSENGER, etc.



MESSENGER

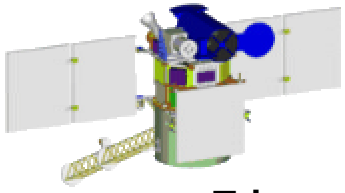


Cultivate international partnerships:
Bepi-Colombo, Venus Climate Observer, Solar Orbiter



Draw upon existing future assets for near-Earth solar wind input:
ACE, WIND, Triana


ACE


Triana

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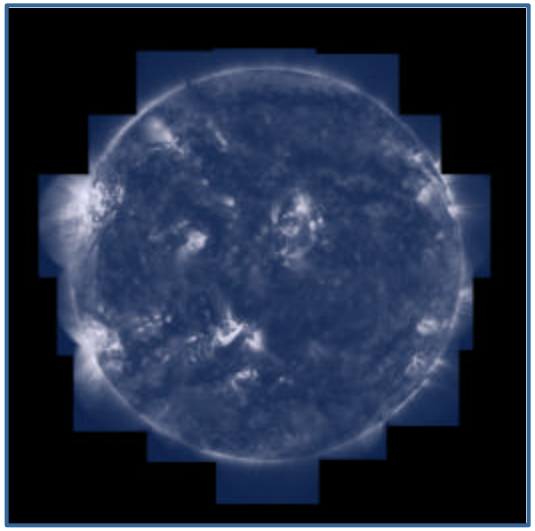
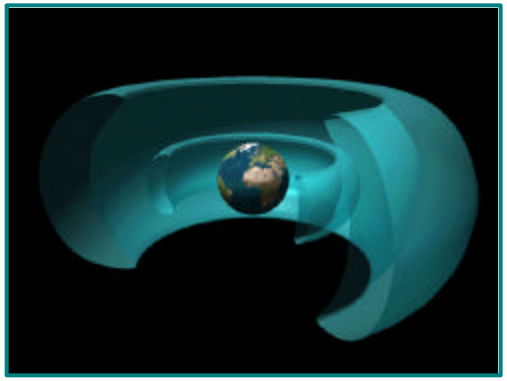
Living With A Star, Targeted Research & Technology aka Theory, Modeling And Data Analysis (TMDA)

Overview

This LWS research program is targeted toward the research needed to refine understanding of space weather and the role of solar variability in terrestrial climate change.



- Improve understanding of space weather and solar variability, and its effect on long term climate change
- Perform research and development to enable improved specification models and predictive capability
- Cover solar atmosphere to Earth's ionosphere
- Develop new instrument techniques, models, and concepts for investigating solar and geospace disturbances.



Yearly Research Opportunities through ROSS NRA

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Living With a Star -

A systematic research program to understand the societal effects of the connected Sun-Earth system

A bold initiative that advances beyond curiosity-driven science

LWS Objectives -

Understand the impact of solar variations on global change

Understand the physical processes linking the connected Sun-Earth system on short time scales

Enable the development of space weather forecasting and nowcasting

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LWS Approach –

Organize the research program along the system-wide themes of:

- global change / climate
- space weather

Design a combined program of theory and observation that delivers comprehensive understanding of the connected Sun-Earth system

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LWS Implementation -

A coordinated set of observations that will:

- **Discover underlying physical processes**
- **Define phenomenology of the system**
- **Deliver inputs, constraints, and verification for theory and models**
- **Define measurements needed for operational system development**

Coordinated theory and modeling activities that will:

- **Understand underlying physical processes**
- **Model phenomenology of the system**
- **Define observations needed to drive and validate models**
- **Deliver models that serve as prototypes for operational systems**

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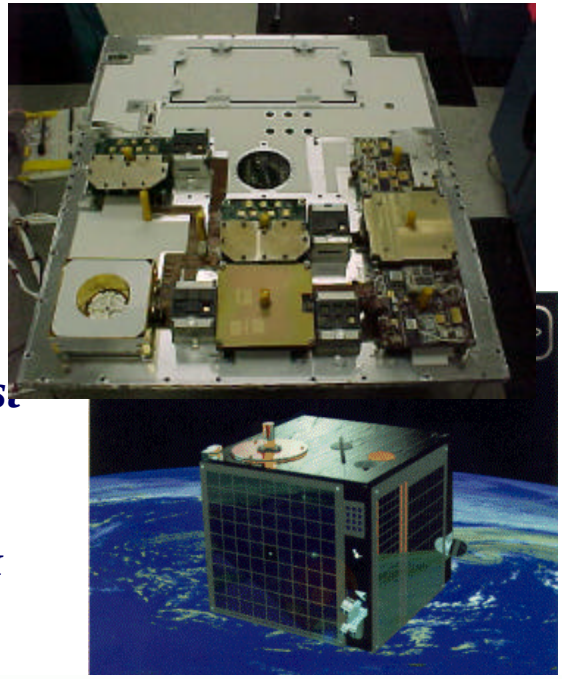
Living With a Star Space Environment Testbeds

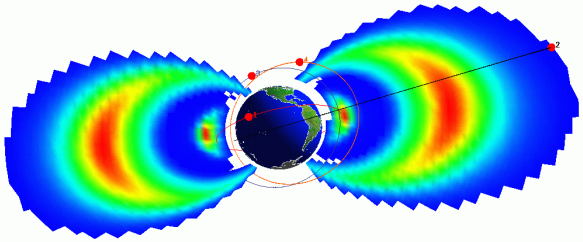
Objective

Improve the engineering approach to accommodate and/or mitigate the effects of solar variability on spacecraft design & operations



Approach

- ***Collect data in space to validate new & existing ground test protocols for the effects of solar variability on emerging technologies & components***
- ***Develop & validate engineering environment prediction & specification models, tools, & databases***
- ***Collect data in space to validate the performance of instruments for LWS science missions & new space technology***



Scope

Spacecraft hardware & design /operations tools whose performance changes with solar variability

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Space Environment Testbed Products

Bridge the Gap Between Science, Engineering, & User Application Communities

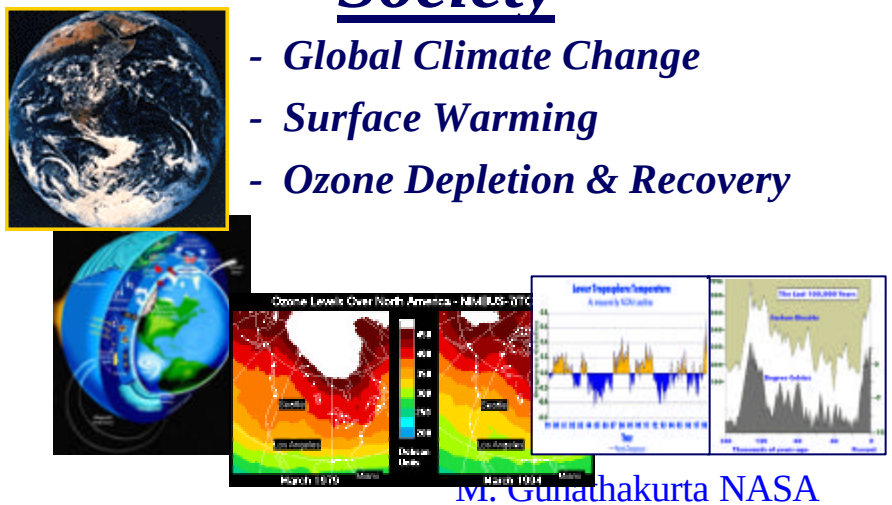
Human Radiation Exposure

- *Space Station*
- *Space Exploration*
- *High Altitude Flight*
- *Space Utilization & Colonization*

Impacts on Technology

- *Space Systems*
- *Communication & Navigation*
- *Aircraft Systems*
- *Ground Systems*

Impacts on Life & Society



- *Global Climate Change*
- *Surface Warming*
- *Ozone Depletion & Recovery*

Space Environment Testbed Implementation

- ***Design modular carrier concepts to capitalize on launch opportunities***
- ***Fly testbed in space every 2 years – Pathfinder in 2004; Competed SET-1 NET 2006***
- ***Hold bi-yearly workshops***
  - *– Requirements definition & partnering*
  - *– Presentations of results*
- ***Fund NASA Research Announcements for induced space environment and effects investigations***
  - *– Categories:*
    - ***Sensors/detectors***
    - ***Materials***
    - ***Spacecraft Charging***
    - ***Ionizing Radiation Effects***
    - ***Induced Environment***
  - *– NRA for SET-1 Experiments Will Be Released on Sept. 17, 2002*
  - *– Awards from NRA for analysis made in January 2002*

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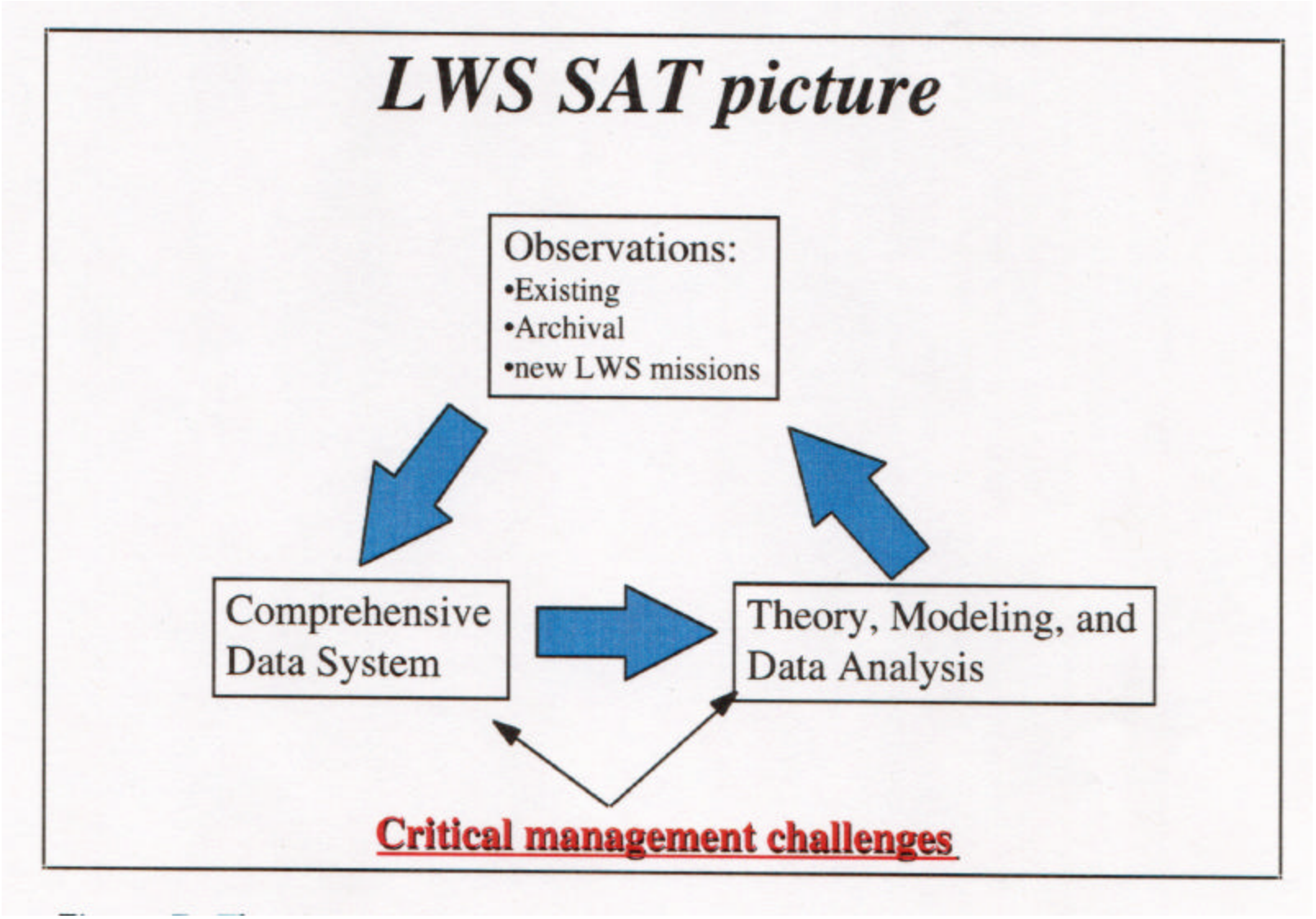
LWS SAT picture
Observations:
•Existing
•Archival
•new LWS missions
Comprehensive Data System
Theory, Modeling, and Data Analysis
Critical management challenges